The ALICE experiment at the LHC: a status review

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Abstract
ALICE is one of the big experiments at the LHC. It focuses on the study of heavy ion collisions at ultra-relativistic energies. Its main goal is to observe a transition of ordinary matter into a plasma of quarks and gluons. Here we review the status of the experiment just before data taking starts. Cosmic ray studies as well as the results of the past beam tests show the potential of the detector.

1 The Large Hadron Collider

The Large Hadron Collider (LHC) [1] accelerates protons in a 27 km long tunnel located in the European Center for Nuclear Research (CERN) at Geneve, Switzerland. The LHC will also accelerate lead ions to make them collide at the highest energy ever.

The acceleration process starts in LINAC 2 for protons and LINAC 3 for lead ions. The protons accelerated in LINAC2, are injected to a Proton Synchrotron Booster with an energy of 50 MeV. In the Synchrotron, protons reach an energy of 1.4 GeV. The Super Proton Synchrotron (SPS) has been modified to deliver a high brightness proton beam, required by the LHC. The SPS takes 26 GeV protons from the PS and brings them to an energy of 450 GeV before extraction.

The LINAC 3 produces 4.2 MeV/u lead ions. LINAC 3 was commissioned in 1994 by an international collaboration and upgraded in 2007 for the LHC. The Low Energy Injector Ring (LEIR) is used as a storage and cooler unit. It provides ions to the Proton Synchrotron with an energy of 72 MeV/nucleon. Ions will be further accelerated by the Proton Synchrotron and the Super Proton Synchrotron before they are injected into the LHC where they reach an energy of 2.76 TeV/nucleon.

The LHC consists of 1232 superconducting dipole magnets with double aperture that operate at up to 9 Tesla magnetic field. The accelerator also includes more than 500 quadrupole magnets and more than 4000 corrector magnets of many types.

The total cross section of proton-proton interaction at 7 TeV could be inferred from hadronic cross section measurements at lower energy [2]. It would be around 110 mbarn and correspond to about 60 mbarn of inelastic scattering cross section. The accelerator, at its design operation, will reach a luminosity of 10^{34} sec^{-1} cm^{-2}, it means that the interaction rate will be:

$$rate = 10^{34}\frac{1}{cm^2 s} \times 60 \times 10^{-3}\,barn \times 10^{-24}\frac{cm^2}{barn} = 600 \times 10^{6}\frac{collisions}{s}$$

A 25 ns interval between bunches gives a 40 MHz crossing rate. On average 19 inelastic events will occur each time bunches cross. Since there will be gaps in the beam structure an average crossing rate of 31.6 MHz will be reached. Detectors at the LHC must be designed to cope with these frequencies. However, ALICE will run at a modest 300 kHz interaction rate in proton proton mode and 10 kHz in Pb-Pb.

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During the fall 2009, bunches of protons will be injected into the LHC ring. During the start up phase, first collisions with protons at 900 GeV will take place. An increase of the proton beam energy in a second phase is foreseen. The energy that will be reached in this phase is still to be decided. By the end of the run with protons in year 2010, lead ion collisions will be produced.

The ALICE experiment is ready to take data on all the phases of the accelerator operation.

2 A Large Ion Collider Experiment

The ALICE experiment has been designed to observe the transition of ordinary matter into a plasma of quarks and gluons [3]. At the energies achieved by the LHC, the density, the size and the lifetime of the excited quark matter will be high enough as to allow a careful investigation of the properties of this new state of matter. The temperature will exceed by much the critical value predicted for the transition to take place.

ALICE has been optimized to study global event features. The number of colliding nucleons will provide information on the energy density achieved. The measurement of elliptic flow patterns will provide information about thermalization on the partonic level and the equation of state of the system in the high-density phase. Particle ratios in the final state are connected to chemical equilibration and provide a landmark on the trajectory of the system in the phase diagram. The space-time evolution of the system can be investigated via particle interferometry, complemented by the study of resonaces. Moreover, important information about the system properties can be obtained by the study of hard probes, which will be produced abundantly at LHC. Deconfinement may be reflected in the abundancies of J/ψ and Upsilon. The study of jet production on an event-by-event basis will allow to investigate the transport properties of hard-scattered partons in the medium, which are expected to be strongly modified if a Quark-Gluon Plasma is formed.

ALICE is also well suited for studies of proton-proton and photon-photon reactions. Photon-Photon reactions include QED and QCD processes that go from lepton pair to hadron and jet production. As for proton-proton interactions, diffractive physics would be an exciting area of research.

The ALICE detector will have a tracking system over a wide range of transverse momentum which goes from 100 MeV/c to 100 GeV/c as well as particle identification able to separate pions, kaons, protons, electrons, muons and photons.
A longitudinal view of the ALICE detector is shown in Fig. 1. A detailed description of the ALICE detector can be found in [4].

In the forward direction a set of tracking chambers inside a dipole magnet will measure muons. An absorber will stop all the products of the interaction except for the muons which travel across and reach the tracking chambers that form the muon arm.

The central part of the ALICE detector is located inside a solenoid that provides a magnetic field of 0.5 T. The central tracking and particle identification system covers $-0.9 < \eta < 0.9$.

Fig. 2 resumes the pseudo-rapidity coverage of the systems in ALICE.

Electrons and photons are measured in the central region: photons will be measured in PHOS, a high resolution calorimeter located 5 *m* below the interaction point. PHOS is built from $PBWO_4$ crystals which have a high light output.

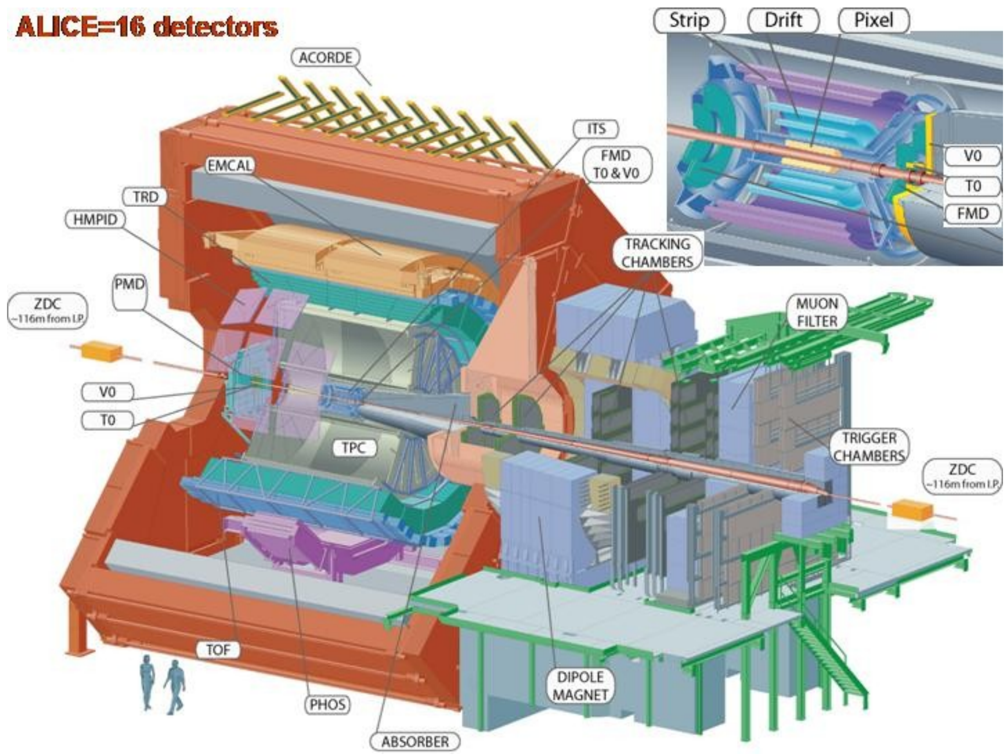

Fig. 1: The ALICE experiment consists of 16 detector subsystems. It combines particle identification, tracking, calorimetry and trigger detectors.

An Electromagnetic Calorimeter which will cover the central barrel is now in construction. Two modules will operate in the 2009 run. EMCAL is made of almost 13,000 towers of plastic scintillators and lead plates in a sandwich array which is read out with wavelength- shifting optical fibres. Avalanche photodiode sensors are used to convert light into an electronic signal.

The track measurement is performed with a set of six barrels of silicon detectors (ITS, Inner Tracking System) and a large Time Projection Chamber (TPC). The TPC has an effective volume of 88 m^3. It is the largest TPC ever built. These detectors will make available information on the energy loss allowing particle identification too. In addition to this, a Transition Radiation Detector (TRD) and a Time of Flight system (TOF) will provide excellent particle separation at intermediate momentum, respectively. The Time of Flight system uses Multi-gap Resistive Plate Chambers with a total of 160,000 readout channels. A Ring Imaging Cherenkov will extend the particle identification capability to higher momentum particles (HMPID). It covers 15% of the acceptance in the central area and will separate pions from kaons with momenta up to 3 GeV/c and kaons from protons with momenta up to 5 GeV/c.

A Forward Multiplicity Detector (FMD) consisting of silicon strip detectors and a Zero Degree Calorimeter (ZDC) will cover the very forward region providing information on the charge multiplicity and energy flow. A honeycomb proportional counter for photon multiplicity (PMD) measurements is located in the forward direction on one side of the ALICE detector.

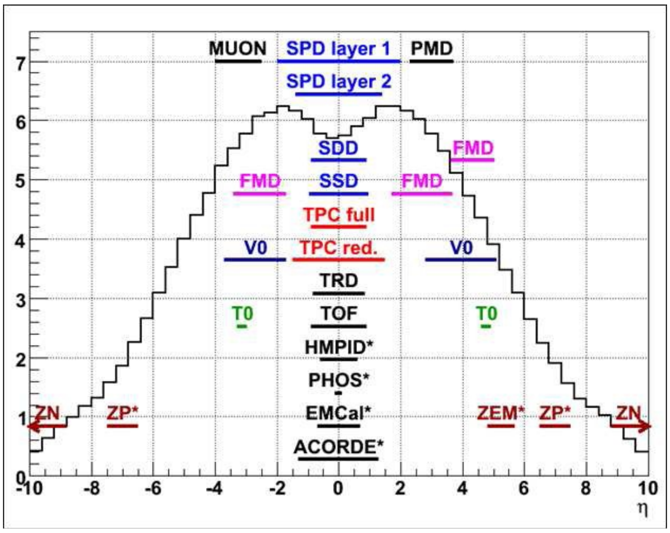

Fig. 2: The ALICE pseudo-rapidity coverage. At very large η Zero Degree Calorimeters (ZN, ZP, ZEM) detect protons and neutrons. ALICE counts on T0, V0, the Forward Multiplicity Detector (FMD) and Photon Multiplicity Detector (PMD) for moderate rapidity $\eta < 5.2$. The central barrel is covered by tracking and particle identification systems as well as by Electromagnetic Calorimeters (EMCal, PHOS).

The trigger system is complemented by a high level trigger (HLT) system which makes use of a computer farm to select events after read-out. In addition, the HLT system provides a data quality monitoring.

The V0 system is formed by two scintillation counters on each side of the interaction point. The system will be used as the main interaction trigger. On top of the magnet, a Cosmic Ray Detector (ACORDE) will signal cosmic muons arrival. We briefly describe these two systems as examples of devices now in operation.

2.1 The V0 system

The V0 system consists of two detectors: V0A and V0C, located in the central part of ALICE. The V0A is installed at a distance of 328 *cm* from the interaction point, mounted in two rigid half boxes around the beam pipe. Each detector is an array of 32 cells of plastic scintillators, distributed in 4 rings forming a disc with 8 sectors. For the V0C, the cells of rings 3 and 4 are divided into two identical pieces that will be read with a single photo-multiplier. This is done to achieve uniformity of detection and a small time fluctuation.

In proton - proton mode the mean number of charged particles within 0.5 units of rapidity is about 3. Each ring covers approximately 0.5 units of rapidity. The particles coming from the main vertex will interact with other components of the detector generating secondary particles. In general, each cell of the V0 detector will, on the average register one hit. For this reason the detector should have a very high efficiency. In Pb-Pb collisions the number of particles in a similar pseudo-rapidity range could be up to 4000 once secondary particles are included. Comparing the number of hits in the detector for proton - proton versus Pb-Pb mode, we can see that the required dynamic range will be 1–500 minimum ionizing particles.

V0 trigger efficiencies are about 89% for detection of at least one charged particle by V0A, 87% for the detection of at least one particle by V0C and 83% for the detection of at least one particle in both, V0A and V0C.

The Hamamatsu photomultiplier tubes are installed inside the magnet not far from the detector. In order to tolerate the magnetic field, fine mesh tubes have been chosen.

The segments of the V0A detector were constructed with a tile technique (see ref. [5]). This technique consists of machining the scintillator plastic and filling the grooves with TiO_2 loaded epoxy in order to separate one sector from the other.

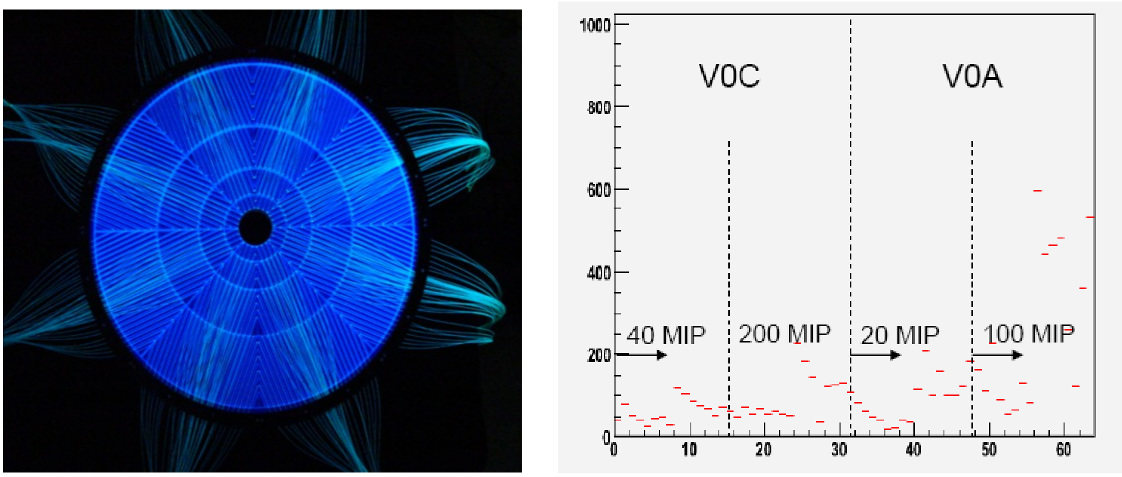

Fig.3: The V0A before optical isolation (left). The segmentation and the optical fibres are visible. On the right side, the ADC map of the V0 system taken during an injection test. In the vertical, the ADC value of each detector cell is plotted. The different values denote different occupancies as one expects from the increase in the active area from inner to outer channels.

A detailed description of the V0 system can be found in [6]. Fig. 3 shows the V0A detector and its performance. On the left the detector before optical isolation gives a view of the granularity. Each cell is read out independently with optical fibers.

During injection tests at the LHC, showers of particles arrived at the detector. The V0 system has collected data during those tests. On the right side of Fig. 3 we can see in the horizontal scale the ADC channels of both V0C (from 0 – 32) and V0A (from 33 – 64). Each entry in the histogram signals the charge collected by that particular cell. All the channels show activity in a regular structure. During these runs the operating voltages are not tuned to exactly same gain, this is why the ADC charge distribution is not smooth. The number with an arrow shows the level of the collected charge for that given number of minimum ionizing particles. As inner cells are smaller than outer ones, the number of particles read out by the corresponding PMT increase. The 4 rings in each detector are visible as jumps in the charge of the ADCs. One can see a good performance for the whole system. The multiplicity per cell increases as expected given the geometry of the detector.

2.2 ACORDE

The Cosmic Ray Detector consists of an array of 60 scintillator counters located in the upper part of the ALICE magnet [7].

The plastic used for the construction of the detector was part of the DELPHI detector. The material was carefully studied and the design of the detector was done according to the capabilities of the plastic available. The material was transported to Mexico where the construction was done.

Each module has a sensitive area of $1.89 \times 0.195\ m^2$ and is built with two superimposed plastics as shown in Fig. 4

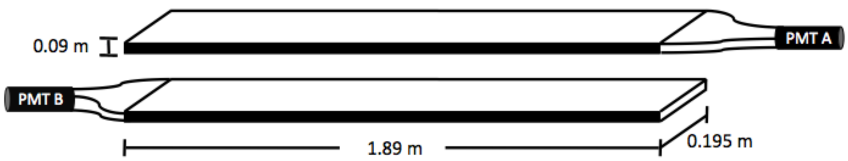

Fig.4: A module of the Cosmic Ray Detector (ACORDE).

The Cosmic Ray Detector:

- Generates a single muon trigger to calibrate the Time Projection Chamber and other components of ALICE.
- Generates a multi-muon trigger to study cosmic rays with the help of tracking systems like the ITS and the TPC.
- Provides a wake-up signal for the Transition Radiation Detector.

The module distribution can be seen in Fig. 5. Modules on the far ends of the inner and outer faces of the magnet were moved to the center of the upper face in order to have a much better efficiency for single muons since the central part of ACORDE was used to align the Inner Tracking System.

Fig.5 shows a real cosmic ray event reconstructed with the Time Projection Chamber and projected to ACORDE on top of the magnet. This event contains 52 muons that fired 38 modules of ACORDE. It was recorded during the cosmic data taken in October 2008. During that period the trigger rate provided by ACORDE was about 100 Hz. Approximately 10 % of the events triggered by ACORDE are registered by the Time Projection Chamber. This is an example of the potential of ALICE for cosmic ray studies using the TPC for the tracking of high multiplicity events.

In August 2009 a two months period of cosmic studies will start. The Cosmic Ray Detector will play a crucial role in triggering interesting events like the one shown here. The commissioning of several systems will be done during this period. Surprises in cosmic ray events could be a bonus before accelerator activities starts in 2009.

3 ALICE Status

The ALICE experiment will start taking data in November 2009. All the systems will be ready but some of them will not be complete. The Transition Radiation Detector will have 8 out of 18 modules installed. The PHOS detector will have 2 out of 5 modules and the Electromagnetic Calorimeter will start with 4 out of 11 modules.

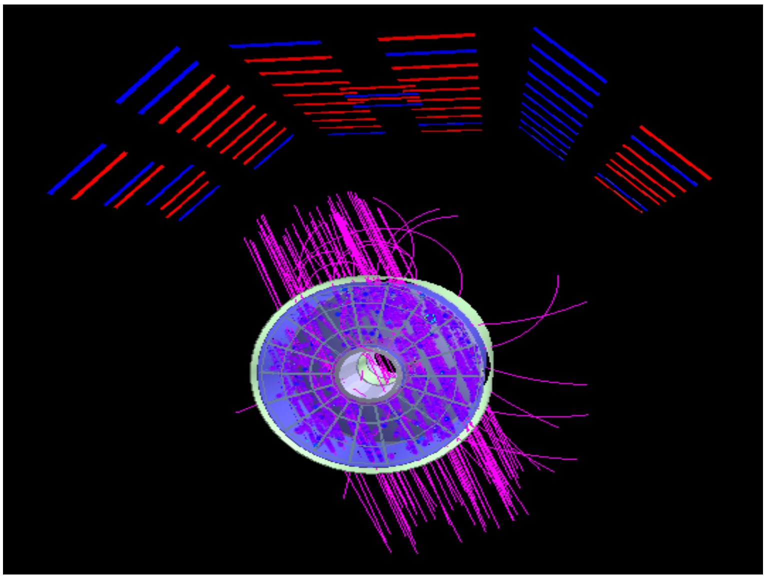

Fig.5: This event was taken during a cosmic run in October 2008. The Cosmic Ray Detector triggered the Time Projection Chamber to register 52 muons.

The missing parts in these systems will be incorporated in the coming breaks of the accelerator. Fig. 6 resumes the status of the ALICE detector at the start of data taken.

As mentioned before, in August 2009 a long cosmic ray run is planned. It will be an opportunity to evaluate the performance of all the systems together. It will also provide a sample of cosmic ray events that will be analysed and carefully studied.

A rich physics program of proton proton collisions has been developed in ALICE. The study of particle production at low transverse momentum is possible thanks to the good efficiency and good resolution in both momentum and particle identification. With the collection of the first proton proton events at 900 GeV, ALICE will measure the multiplicity and p_T distributions.

The first Pb Pb collisions are expected by 2010. With one day of data ALICE would be able to provide global event properties such as events multiplicity, rapidity distributions and elliptic flow. More information on particle spectra, resonance production and interferometry would be extracted after one week of lead - lead collisions which would amount to 1 million events.

In the year 2015, an upgrade of the Large Hadron Collider is foreseen. The luminosity of the accelerator LHC will be increased by an order of magnitude. The detectors must cope with the increase in rate. The ALICE collaboration has started an upgrade program of the detector. Several new ideas are now under discussion.

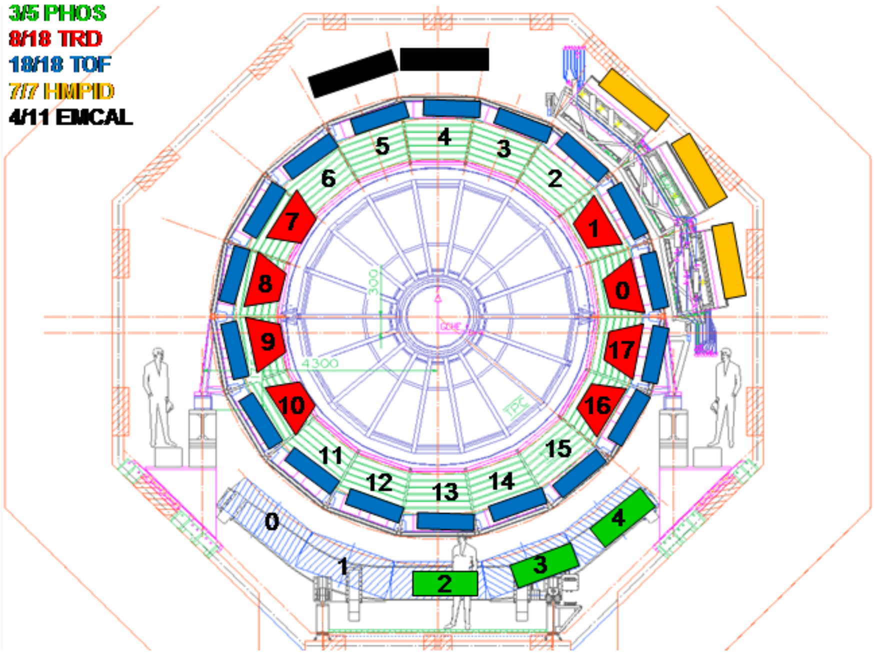

Fig. 6: The ALICE detector as it will be in November 2009 for the data taking with the LHC in operation. The TRD, PHOS and EMCAL will be partially installed.

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